Costs and Benefits of Commissioning New and Existing Commercial Buildings

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Commissioning is *Quality Assurance*

- Articulating/verifying design intent
- Construction observation; warranty enforcement
- Controlling first cost
- Training operators
- Optimizing performance (comfort, reliability, safety, energy)
- Enhancing safety and risk management

History

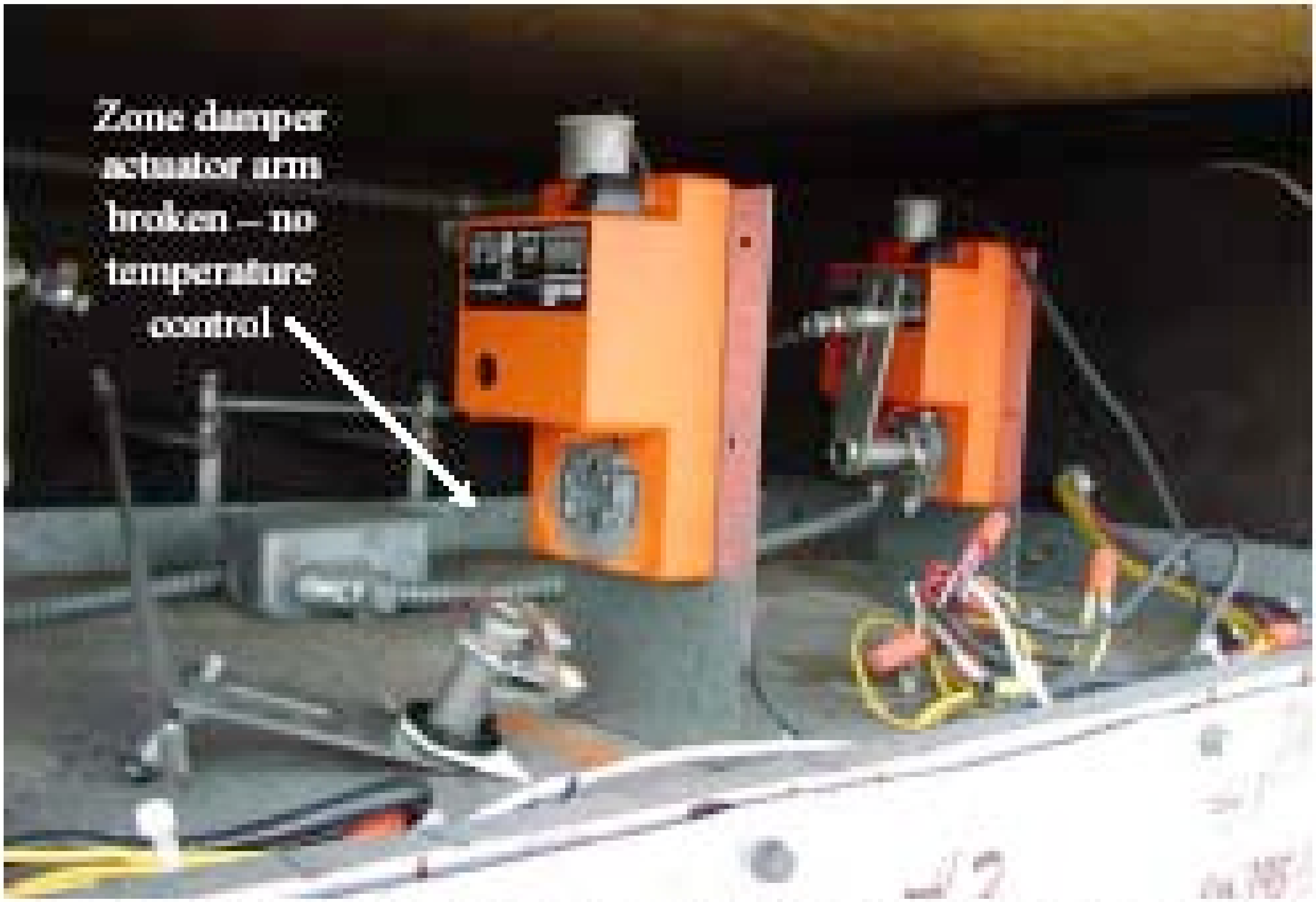
- Born in ship-building industry
- Originally applied in buildings in early 1980s to ensure performance of energy efficiency measures
- Later realized that “ordinary” buildings could achieve energy savings by correcting deficiencies
- Many initiatives/drivers:
  - R&D (e.g. California PIER)
  - Utility programs
  - LEED (required step)
  - California Green Buildings Executive Order and Green Buildings Action Plan
  - California Commissioning Collaborative

Perhaps the single most important outstanding question is:
“Is it Cost-Effective?”

Is There a Need?

- Building problems (a.k.a. “deficiencies”) are *pervasive*
  - *Design flaws; Construction defects; Malfunctioning equipment; Deferred maintenance*
    - *Don’t shoot the messenger: problems a combined result of fragmentation/specialization of trades, “value” engineering, increasingly complex building design and operation requirements, lack of clear design-intent documentation and performance targets, etc.*
- Not attending to problems can cause:
  - Discomfort --> Eroded productivity, absenteeism
  - Indoor air quality problems
  - Premature equipment failure
  - Litigation
  - Excessive energy and construction costs
- Many problems can be cost-effectively remedied

Broken Dampers



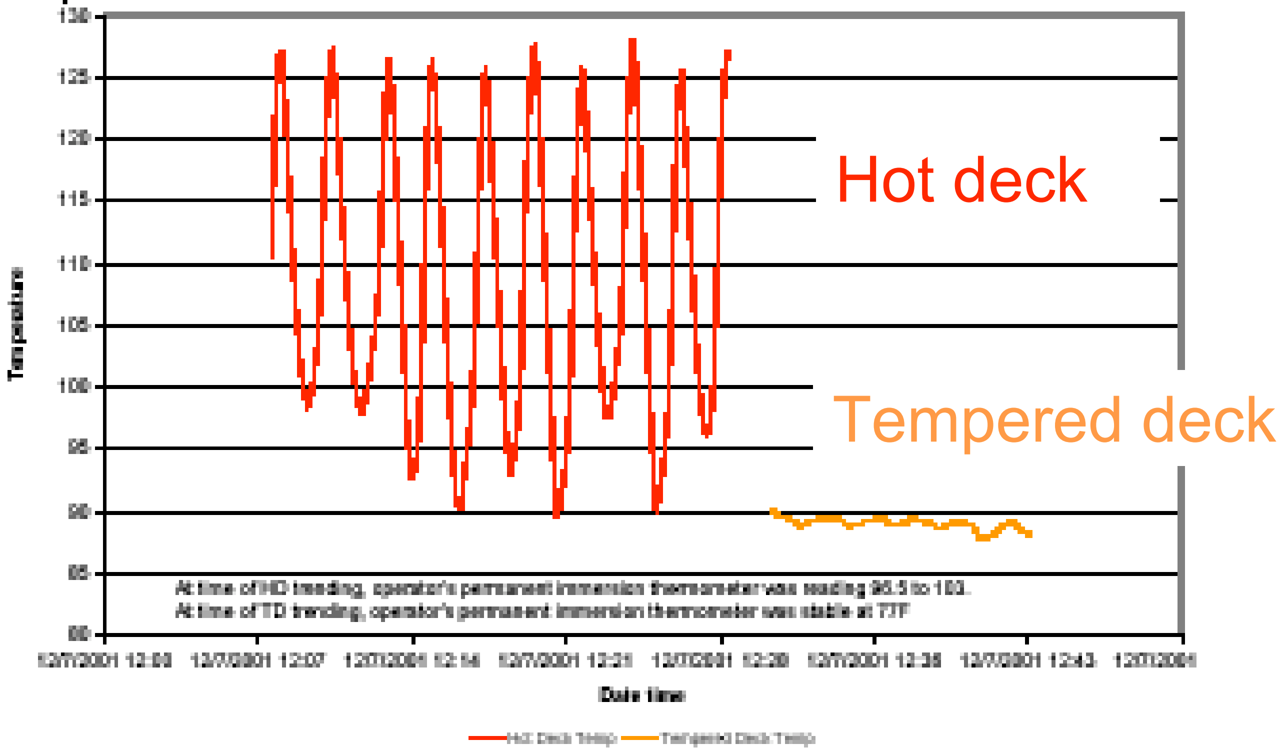
Broken actuator arm on damper of multizone unit, elementary school

Fouled filters

Condensation damage from DX fan coil unit due to plugged filter and low air flow. Large high school.

Faulty controls

Temperature



Hunting of hot deck temperatures with pneumatic control due to sensor thermal mass, steam valve sizing, and controller proportional band. Older high-rise office building.

Poor Coordination Among Trades

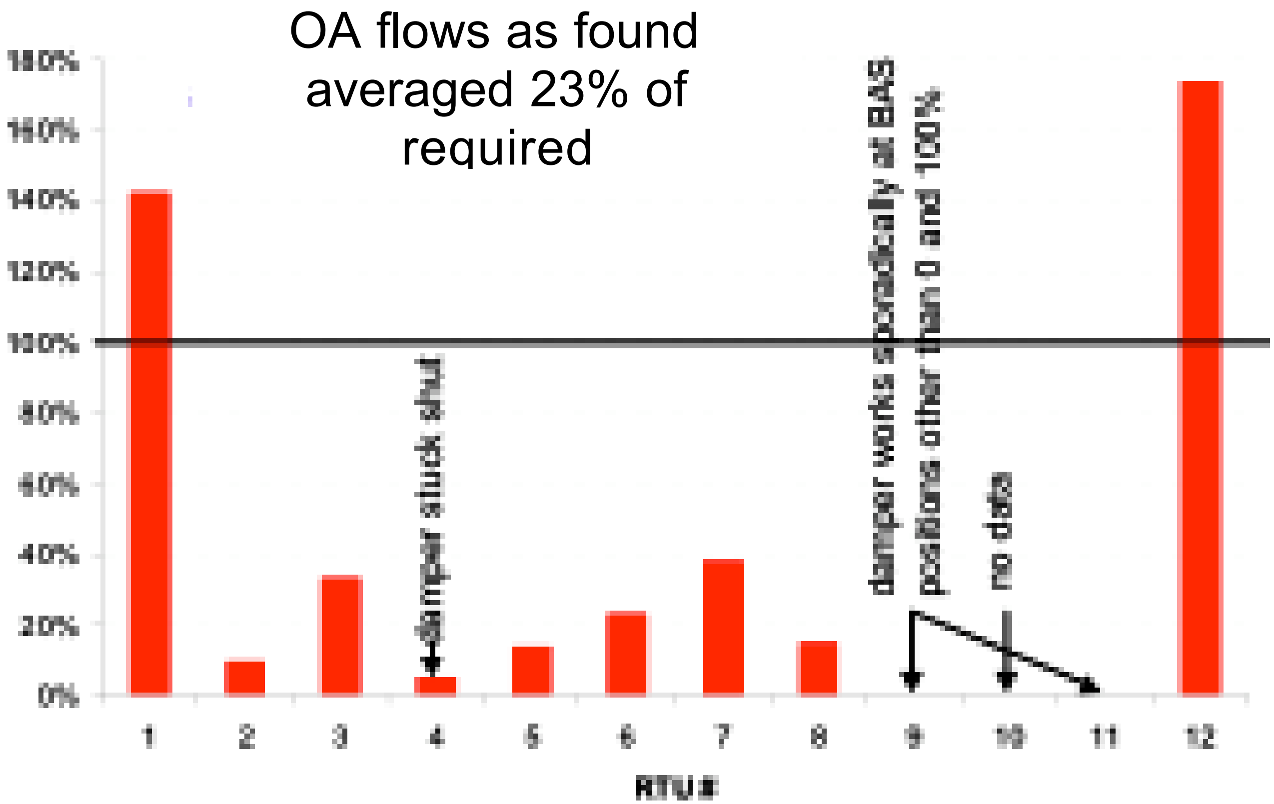
Inadequate cooling and excessive fan power consumption due to poor fit between light troffer diffusers and duct boot provided by a different supplier, allowing up to 25% of flow at diffuser to bypass directly into ceiling plenum. Highrise office tower.

Envelope: air leakage and moisture management

Damage to brick facade of pool building due to lack of specification for (a) sealing of air leakage paths in exterior envelope and (b) balancing to assure negative pressurization of pool area. Large newer middle school.

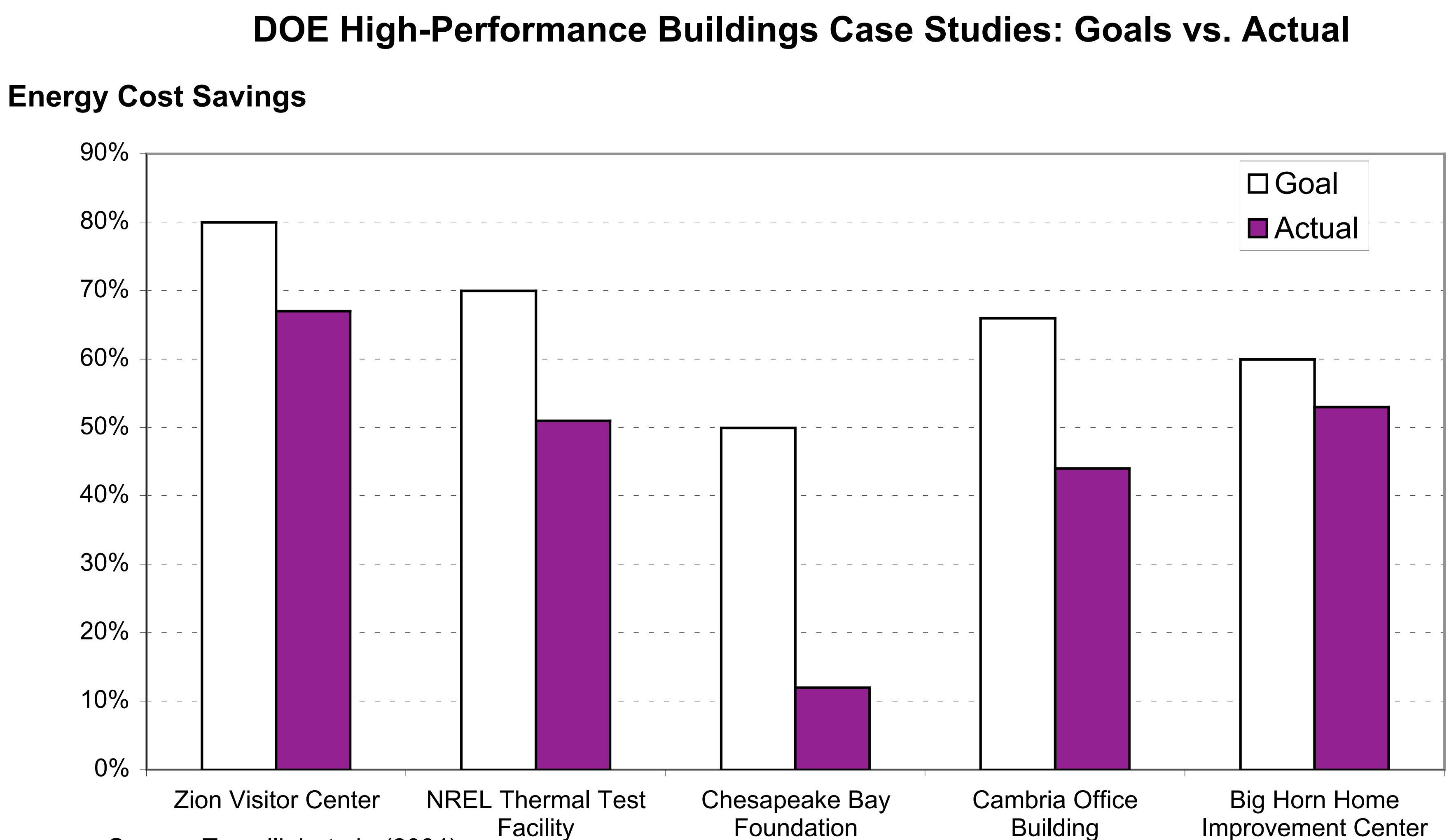
Design-operation mismatch

Actual/Required
air flow



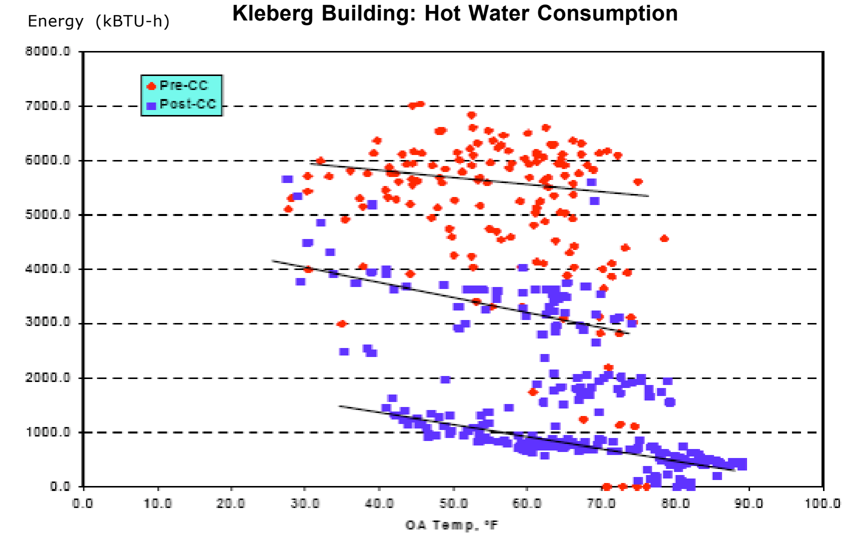
Outside air flows as a percent of required air flow for current occupancy and ventilation standards. Twelve rooftop units at an elementary school.

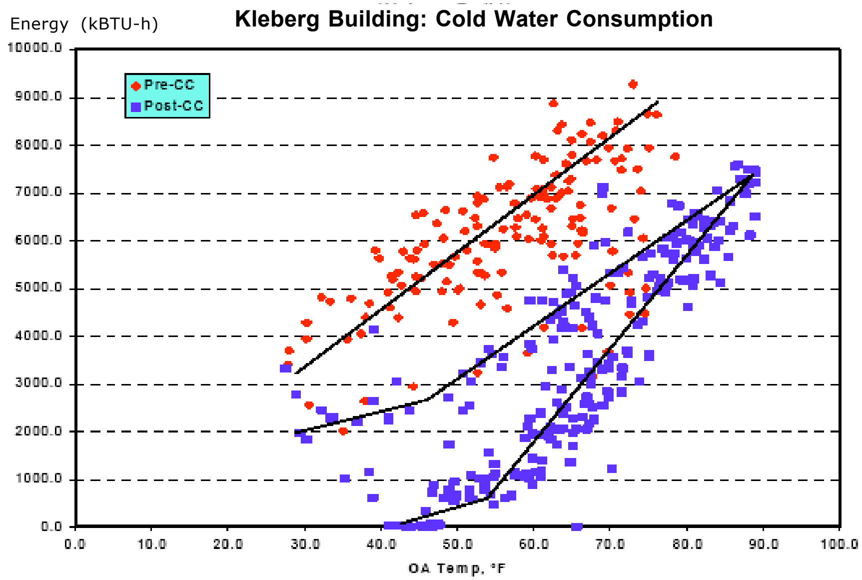
Energy consequences



Source: Torcellini *et al.* (2004)

Case Study: Kleberg Building





INITIAL CONDITION - upper [red] clouds
- Continuous preheat - 105F (intentional)

PHASE 1 MEASURES - middle [blue]
- Preheat off

PHASE 2 MEASURES - lower [blue]
- Preheat to 40F
- Optimize cold deck temps
- Reactivate economizer mode
- Static pressure optimization
- Night-time setback
- Replaced or repaired VFD boxes
- Restarted chilled water VFD
- CHW pump control staging
- Building stack pressure reduced
- Fume hood exhaust pressure reduced

IMPACTS
- **Chilled water: 64% reduction**
- **Hot water: 84% reduction**
- **$314,000 annual energy cost savings**

Main Characteristics of Our Study

- Meta-Analysis (some primary information)
- Focus on energy aspects, but also non-energy <u>impacts</u>
- Separate treatment of existing and newly constructed buildings
- Standardized analysis (definitions, normalized energy prices, inflation) -- has significant effect on results
- Extensive statistical and correlation analyses

Methodology

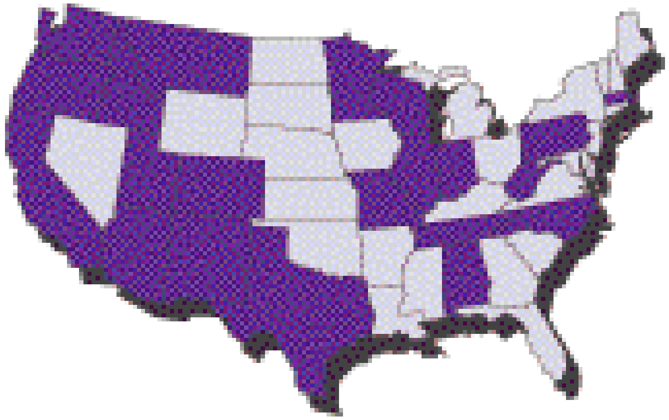
- Establish metrics
- Develop standardized language for describing Cx scope
- Develop standardized framework for characterizing deficiencies and measures ("Measures Matrix")
- Design data instrument to collect required information
- Collect data: from the literature and Cx providers
- Review data quality
- Perform normalizations
  - Standardized energy prices
  - Construction costs corrected for inflation ($2003)
  - Commissioning costs corrected for inflation ($2003)
- Analysis and inter-comparisons (including IPMVP bins)
- Analyze subgroups (new/existing; building type)
- Identify correlations (or lack thereof)
- Identify data gaps

Information Compiled (top level, ~ 200 fields)

- Commissioning provider
- Building type, size, location
- Costs of commissioning (all parties)
- Normalization data (prices, years, weather)
- Observed benefits
  - Energy (IPMVP classifications, or estimates)
  - non-energy
- Commissioning Scope
- Measures Matrix
  - Types of problems (“deficiencies”) discovered
  - Types of interventions (“measures”) implemented

Resulting Sample Characteristics

- 224 buildings (175 projects), of which 150 are existing buildings and 74 are new construction
  - 18+ commissioning providers
  - Largest sample yet compiled
- Diversity of building types (heavy on public buildings)
- 30.4 million square feet across 21 U.S. states
  - Existing buildings: median 151,000 ft^2
  - New construction: median 69,500 ft^2
- $17 million investment
- Projects span two decades, but most done in the 1990s



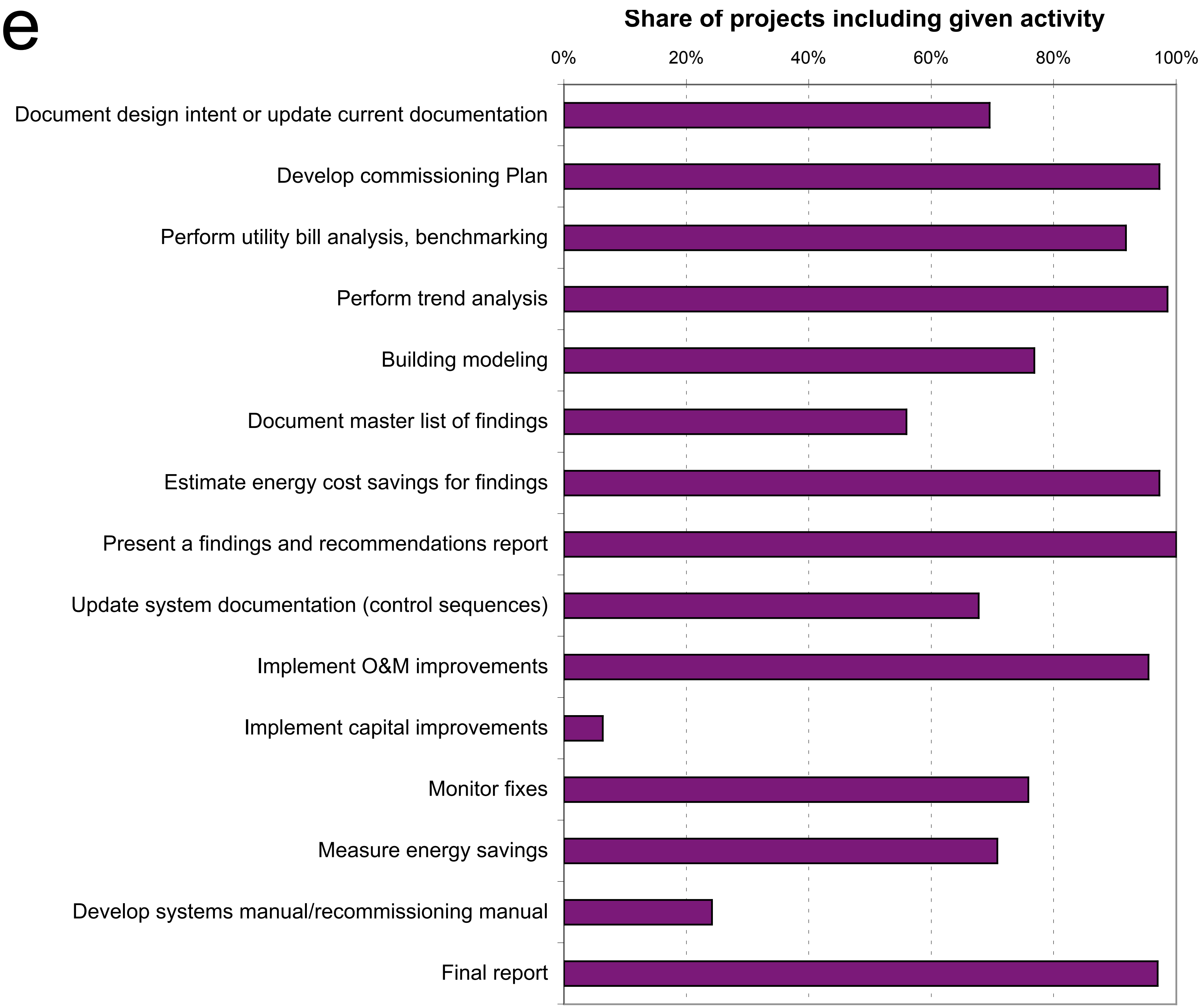
Top-level Findings

- Existing Buildings
  - Cost: \$0.27/ft^2 • Median NEBs: \$0.18/ft^2
  - Deficiencies: 11 per building
  - Energy Savings: 15%
  - Payback: 8.5 months
- New Construction
  - Cost: \$1.00/ft^2 • Median NEBs: \$1.24/ft^2
  - Deficiencies: 28 per building
  - Payback: 4.8 years
- Cost-effective over range of energy intensities, bldg types, sizes, locations
- Most successful: energy-intensive buildings
- Cost-effective outcomes harder in small buildings
- Energy savings rise with more thorough commissioning

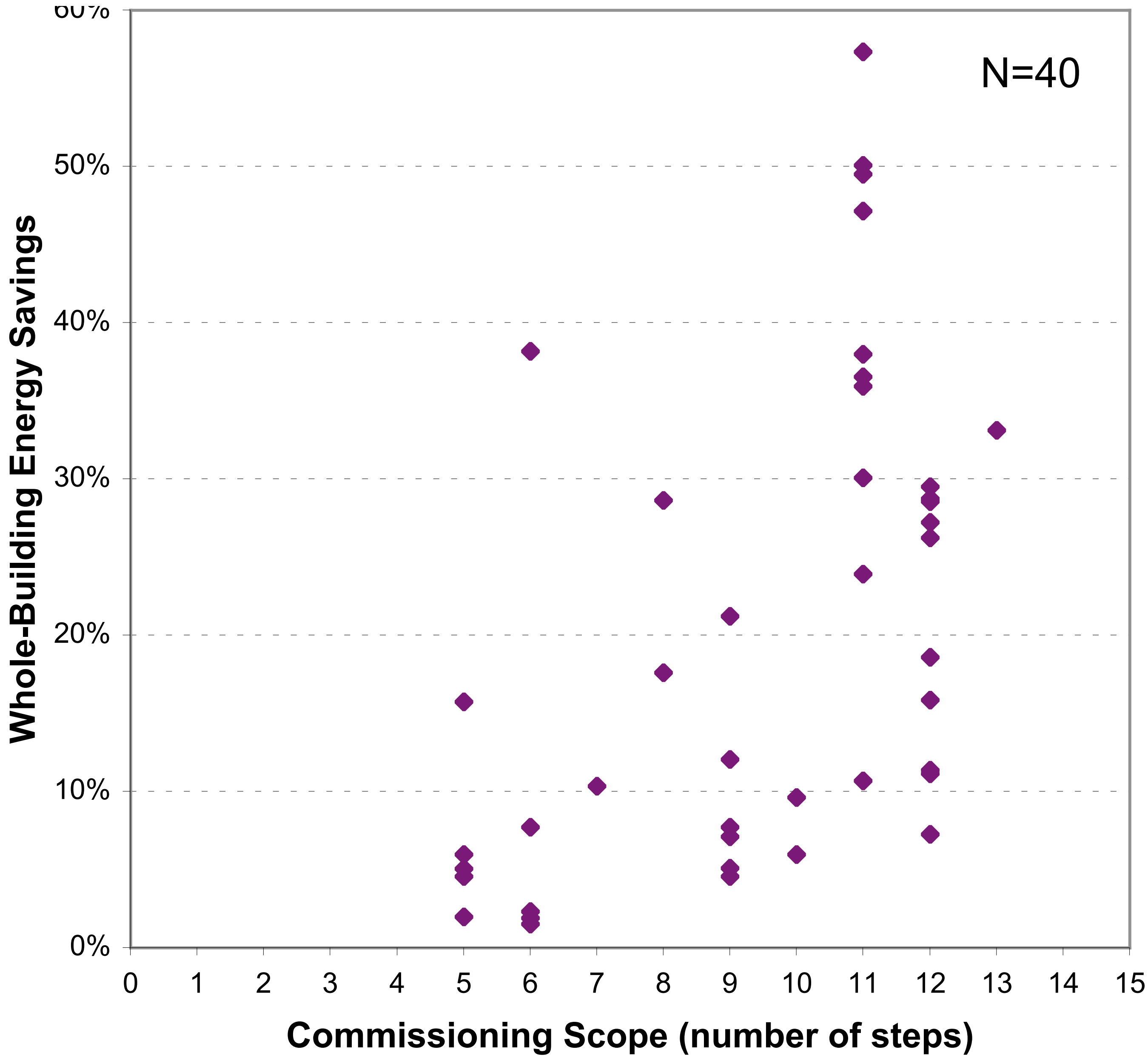
Commissioning Scope: Existing Buildings

- Develop or update design intent documentation
- Plan
- Utility analysis, benchmarking
- Trend analysis
- Building modeling
- Findings
- Estimate benefits from interventions
- Update system documentation (e.g. control sequences)
- O&M improvements
- Capital improvements (grey zone)
- Monitor fixes
- Measure impacts
- Systems manual/recommissioning manual
- Report

Scope


Share of projects including given activity
0%
20%
40%
60%
80%
100%
Document design intent or update current documentation
Develop commissioning Plan
Perform utility bill analysis, benchmarking
Perform trend analysis
Building modeling
Document master list of findings
Estimate energy cost savings for findings
Present a findings and recommendations report
Update system documentation (control sequences)
Implement O&M improvements
Implement capital improvements
Monitor fixes
Measure energy savings
Develop systems manual/recommissioning manual
Final report

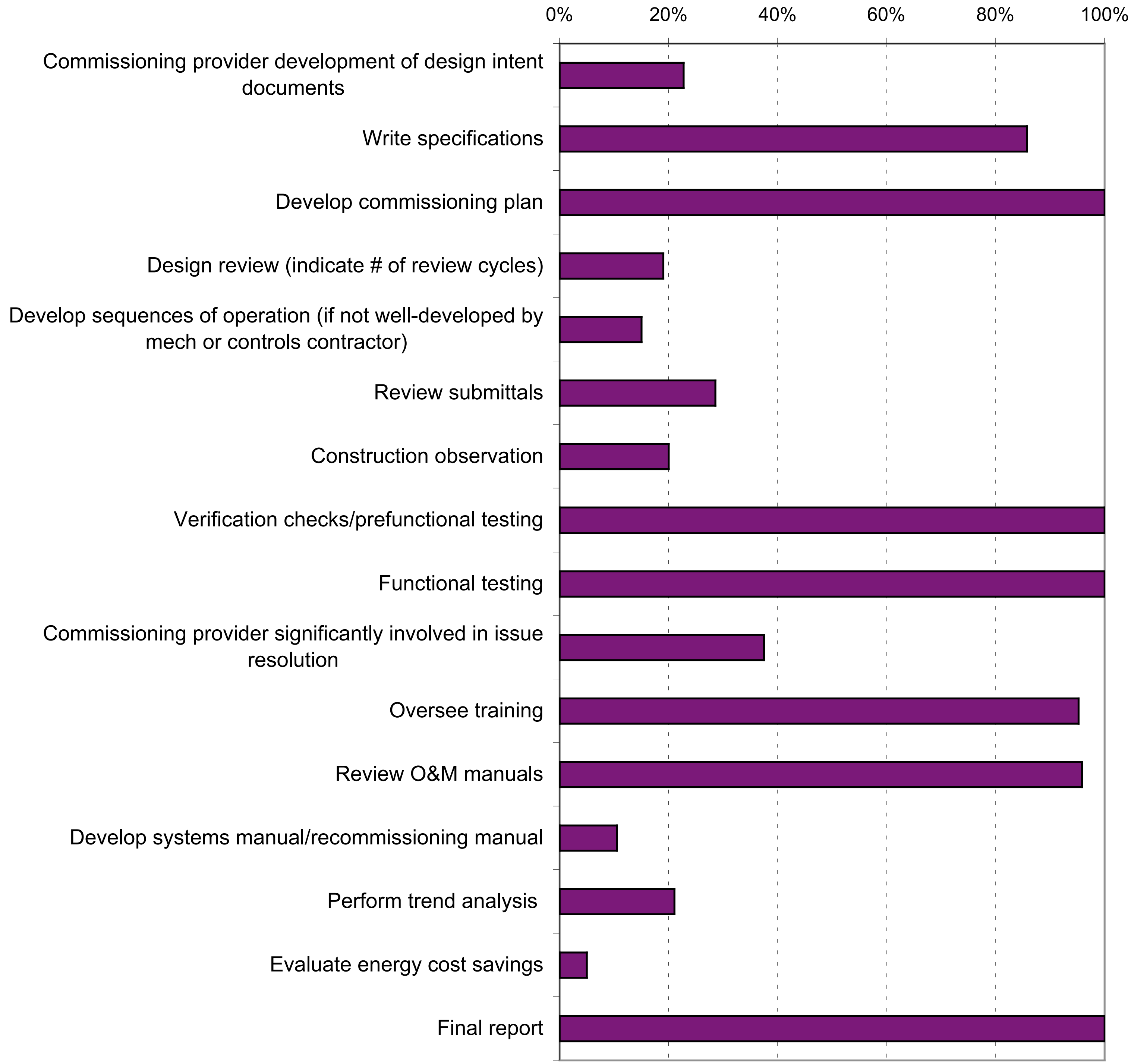
Savings Scale with Commissioning Scope



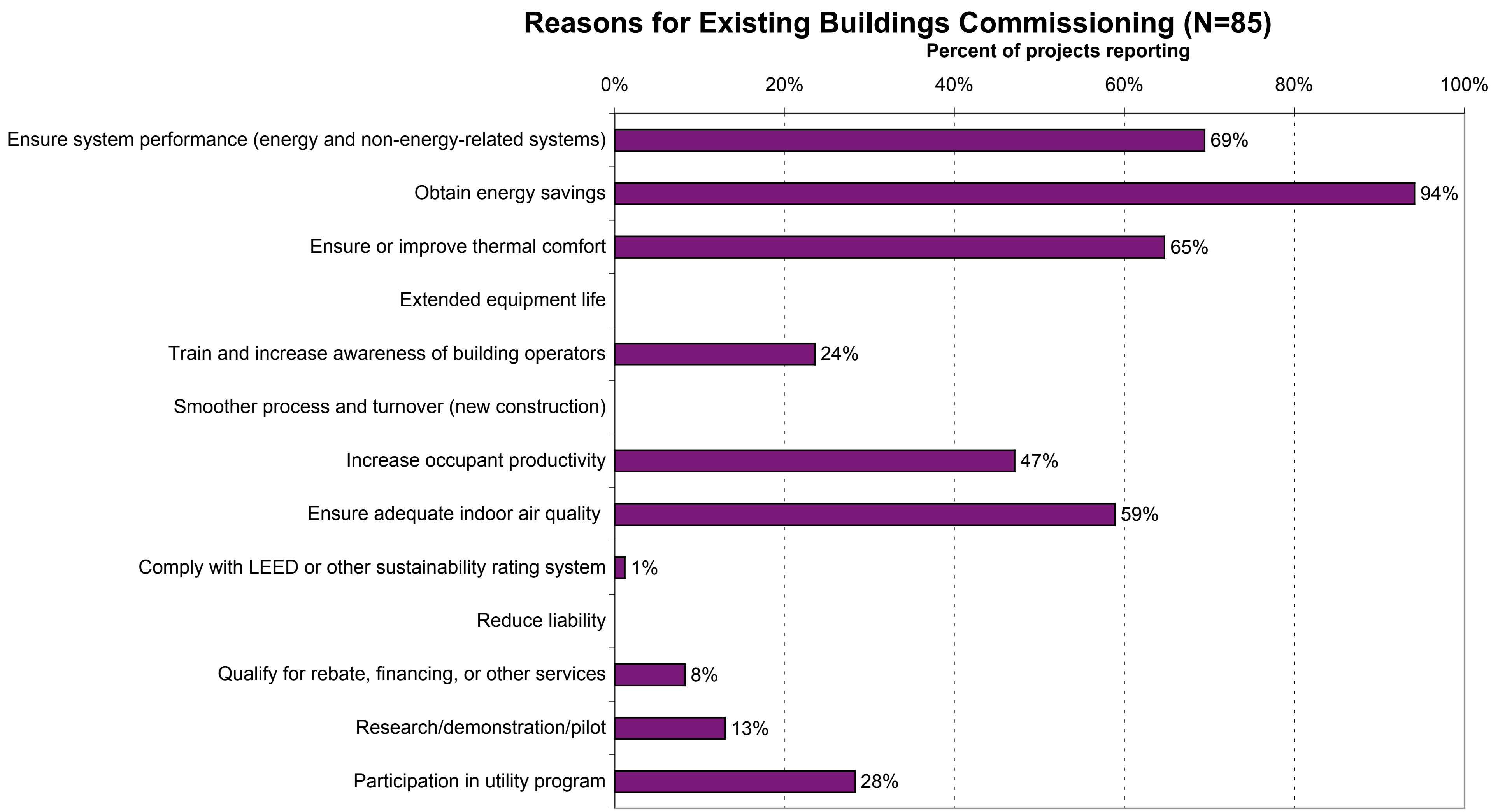
Commissioning Scope: New Construction

- Develop design intent documents
- Specifications
- Plan
- Design review
- Sequences of operation (if not already available)
- Review submittals
- Construction observation
- Verification checks
- Functional testing
- Issue resolution
- Training
- Review O&M manuals
- Systems manual/recommissioning manual
- Trend analysis; evaluate energy savings
- Report

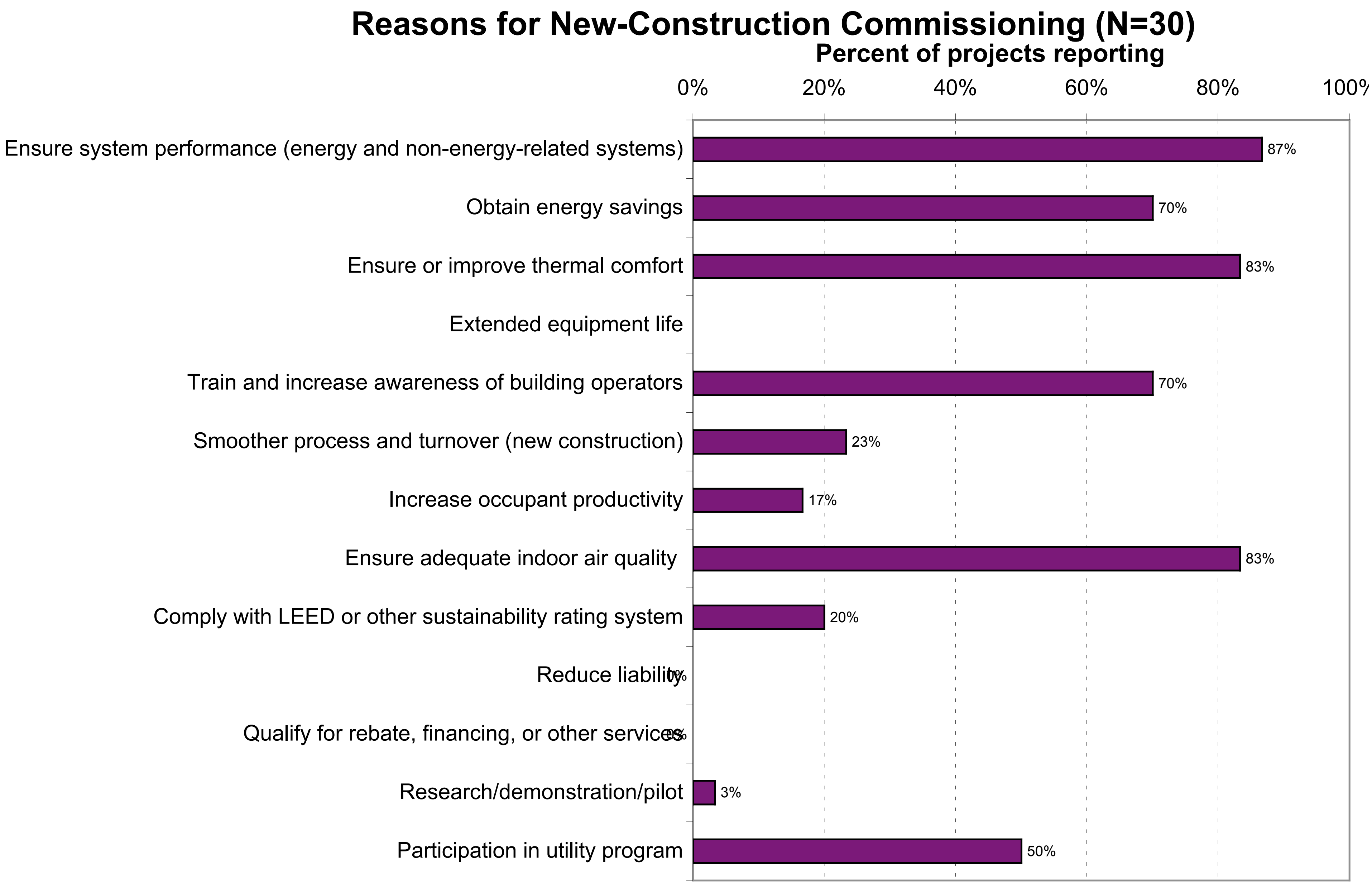
Scope


0%
20%
40%
60%
80%
100%
Commissioning provider development of design intent documents
Write specifications
Develop commissioning plan
Design review (indicate # of review cycles)
Develop sequences of operation (if not well-developed by mech or controls contractor)
Review submittals
Construction observation
Verification checks/prefunctional testing
Functional testing
Commissioning provider significantly involved in issue resolution
Oversee training
Review O&M manuals
Develop systems manual/recommissioning manual
Perform trend analysis
Evaluate energy cost savings
Final report

Drivers: Existing Buildings

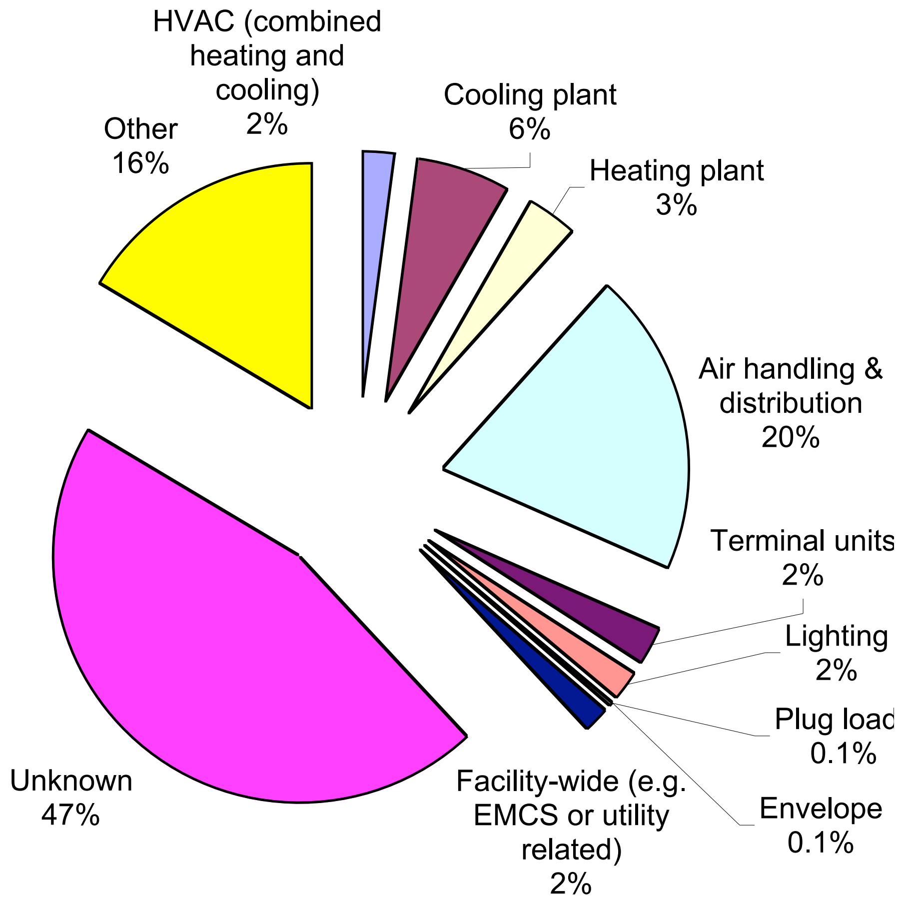


Drivers: New Construction

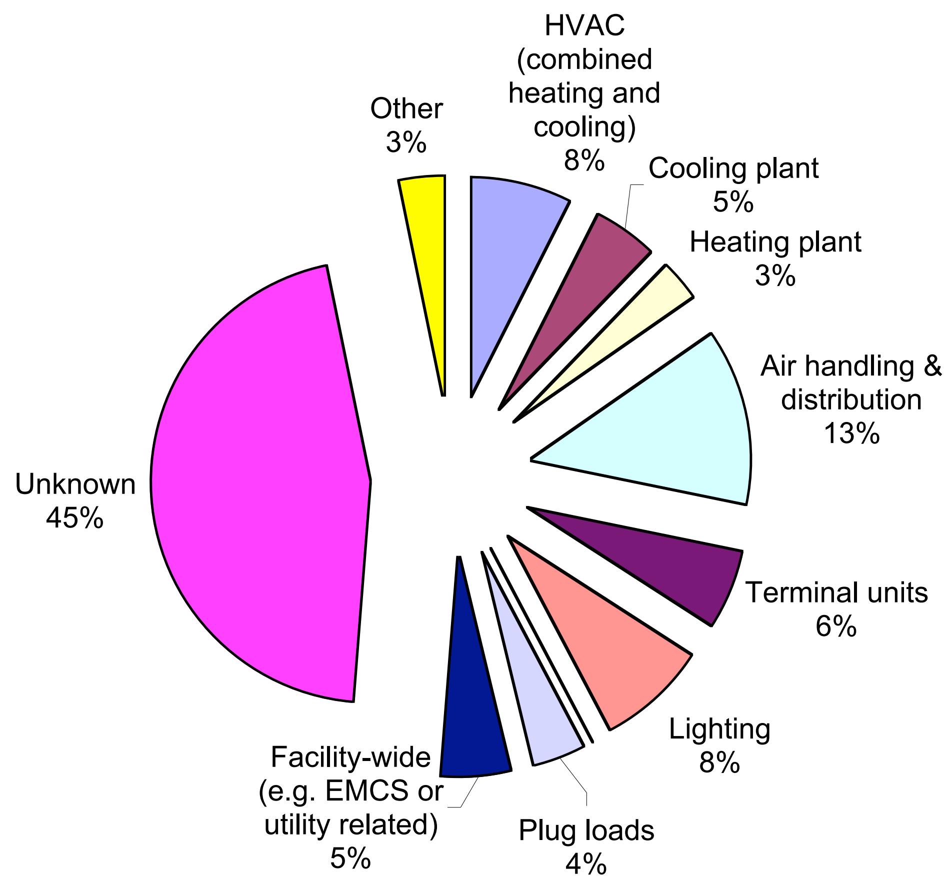


Types of Deficiencies Discovered

Number of Deficiencies Identified by Building System (Existing Buildings, N = 3,500)



Number of Deficiencies Identified by Building System (New Construction, N = 3,305)



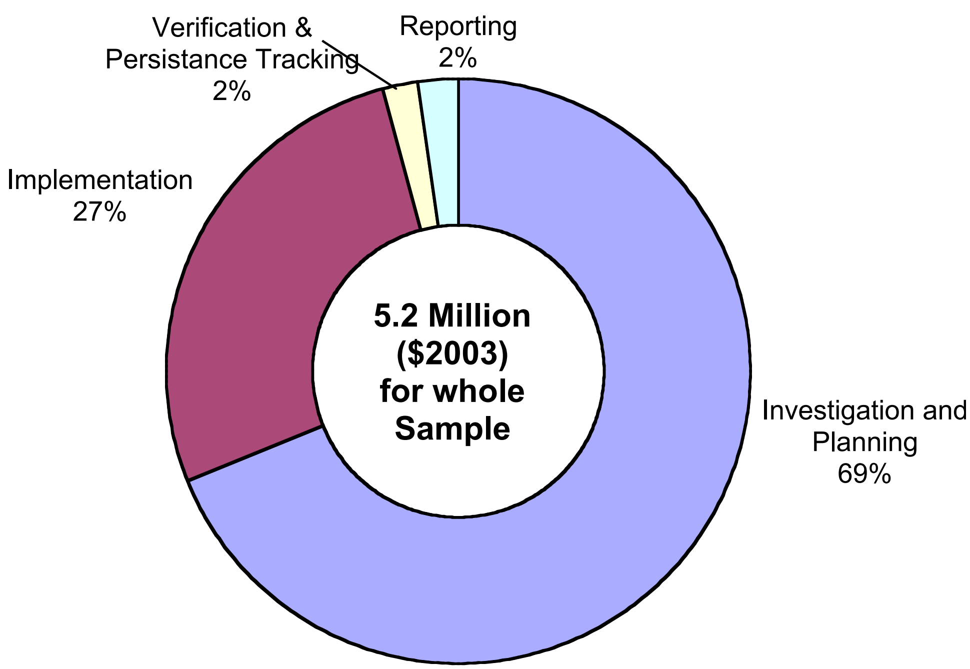
Results from Measures Matrices: Existing buildings (69 projects) [yellow highlights indicate most common measures, deficiencies, and combinations].

N (paired) = 702

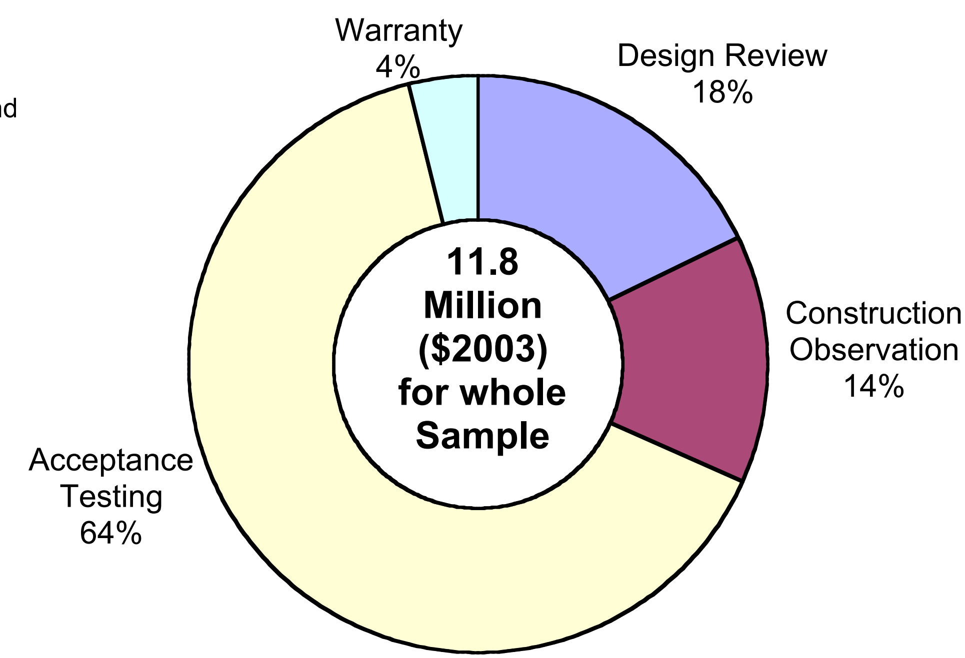
Deficiencies		Design, Installation, Retrofit, Replacement				Operations & Control									Maintenance					Deficiency unmatched to specific measure	Total
		Design change	Installation modifications	Retrofit/equipment replacement	Other	Implement advanced reset	Start/Stop (environmentally determined)	Scheduling (occupancy determined)	Modify setpoint	Equipment staging	Modify sequence of operations	Loop tuning	Behavior modification/manual changes to operations	Other	Calibration	Mechanical fix	Heat transfer maintenance	Filtration maintenance	Other		
		D1	D2	D3	D4	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	M1	M2	M3	M4	M5		
HVAC (combined heating and cooling)	V	0	2	8	1	1	1	5	3	1	5	0	0	2	5	7	1	5	2	12	61
Cooling plant	C	4	11	19	0	26	5	4	10	4	27	3	12	2	4	10	1	0	0	13	155
Heating plant	H	4	0	5	0	15	7	1	4	0	7	1	5	1	4	7	1	0	0	18	80
Air handling & distribution	A	15	9	19	3	80	9	21	25	4	24	12	14	6	40	27	3	4	2	40	357
Terminal units	T	1	3	2	1	4	0	3	14	0	4	1	2	1	7	10	0	0	0	8	61
Lighting	L	3	1	17	1	1	2	4	0	0	0	0	5	0	2	1	0	0	0	1	38
Envelope	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plug loads	P	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Facility-wide (e.g. EMCS or utility related)	F	2	3	2	0	1	0	7	0	0	1	1	7	2	2	2	1	0	0	3	34
Other	O	0	0	2	0	0	0	0	2	0	1	0	1	0	0	3	0	0	1	12	22
Deficiency unmatched to specific measure		10	9	7	0	2	2	1	29	2	7	2	4	1	12	10	0	0	0		809
Total		39	38	81	6	130	26	46	87	11	76	20	51	15	76	77	7	9	5	800	

Cost Allocation

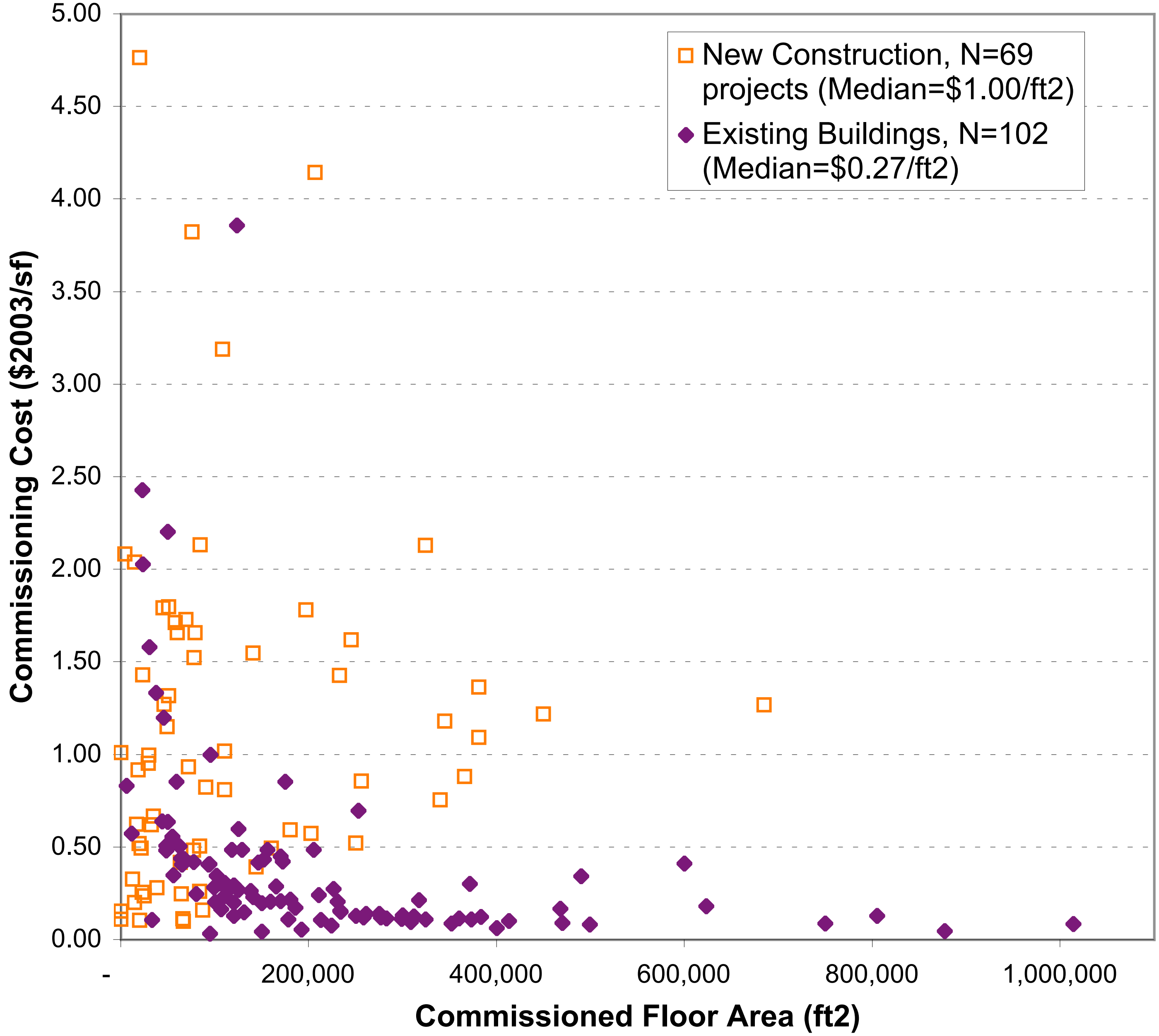
Existing Buildings (N=55)



New Construction (N=5)

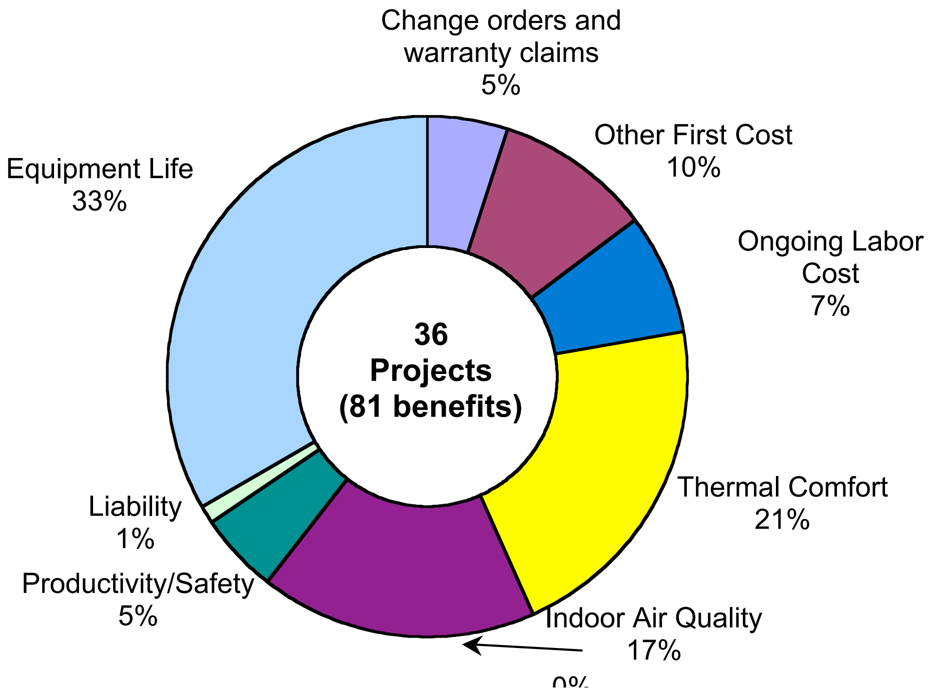


Normalized Costs

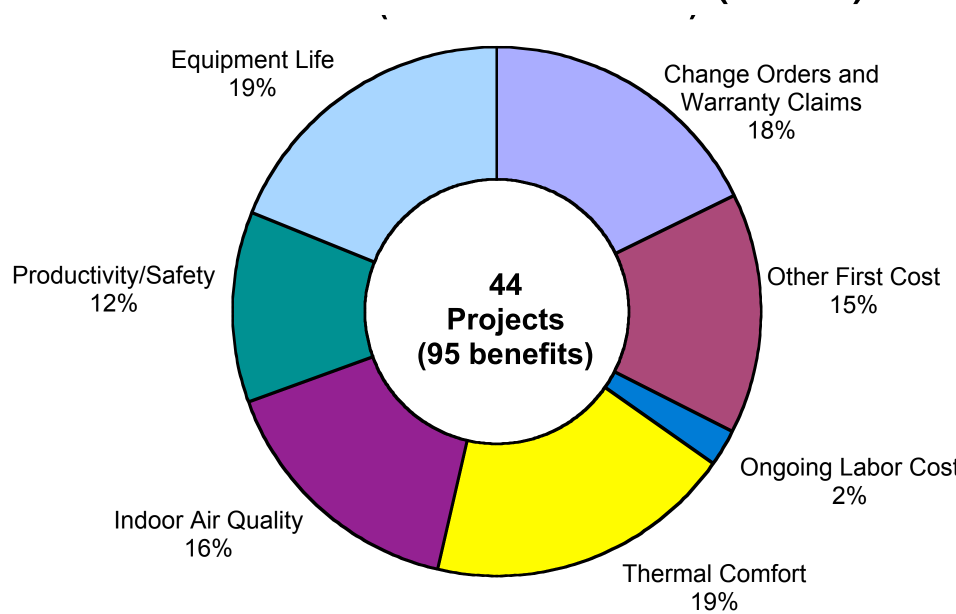


Observed Non-Energy Impacts

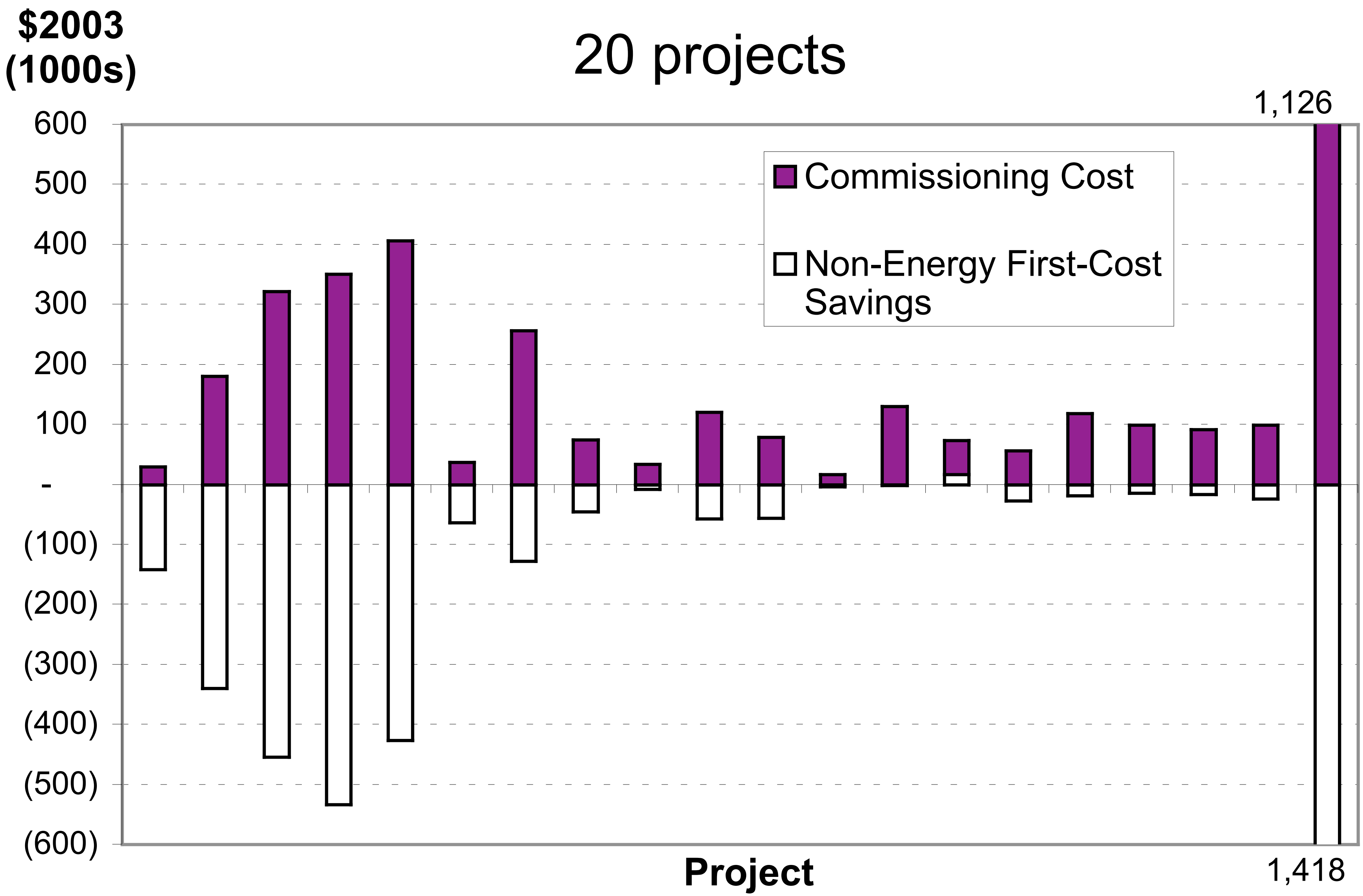
Existing Buildings (N=55)



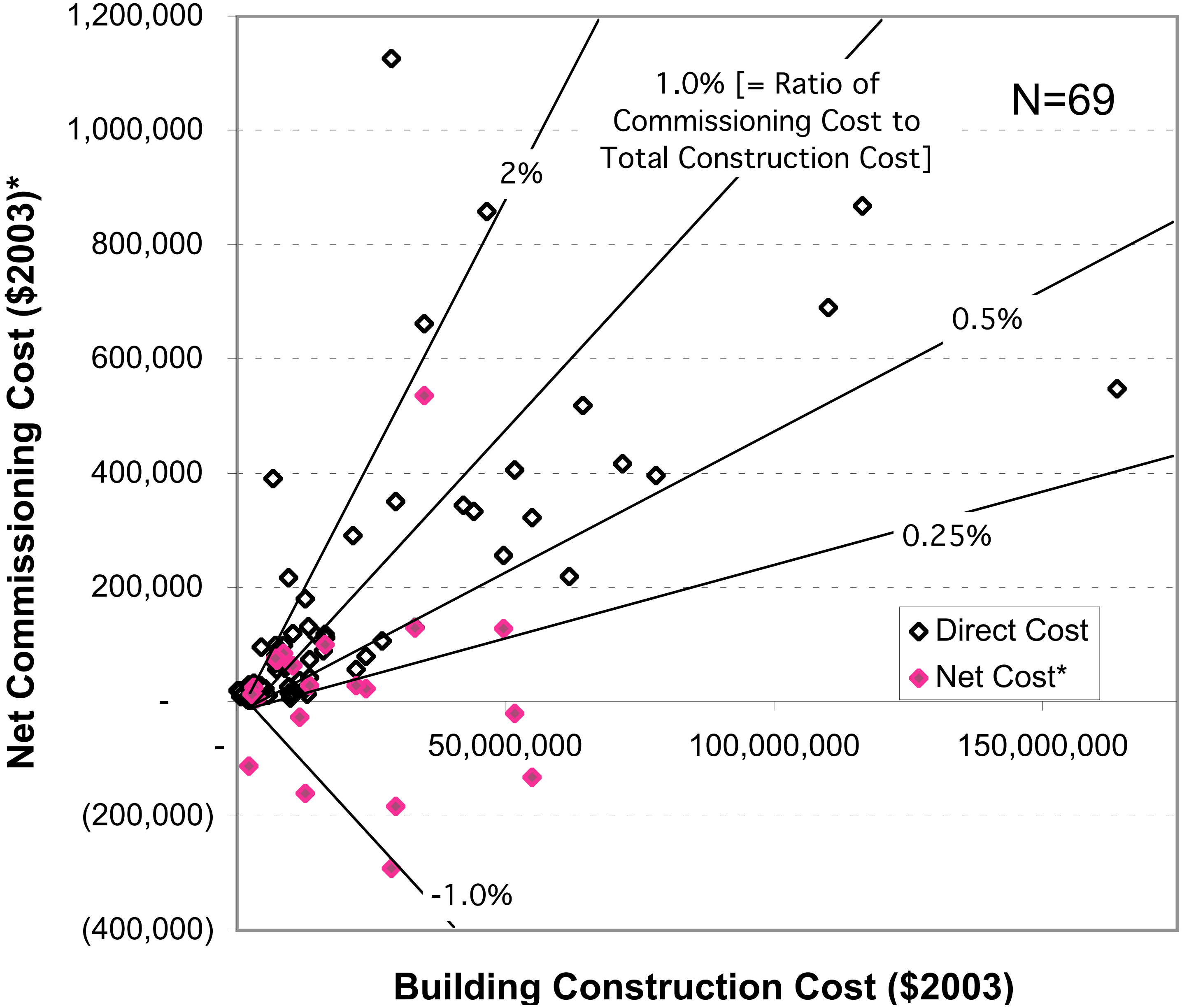
New Construction (N=5)



Non-Energy Benefits Often Offset Cost of Commissioning

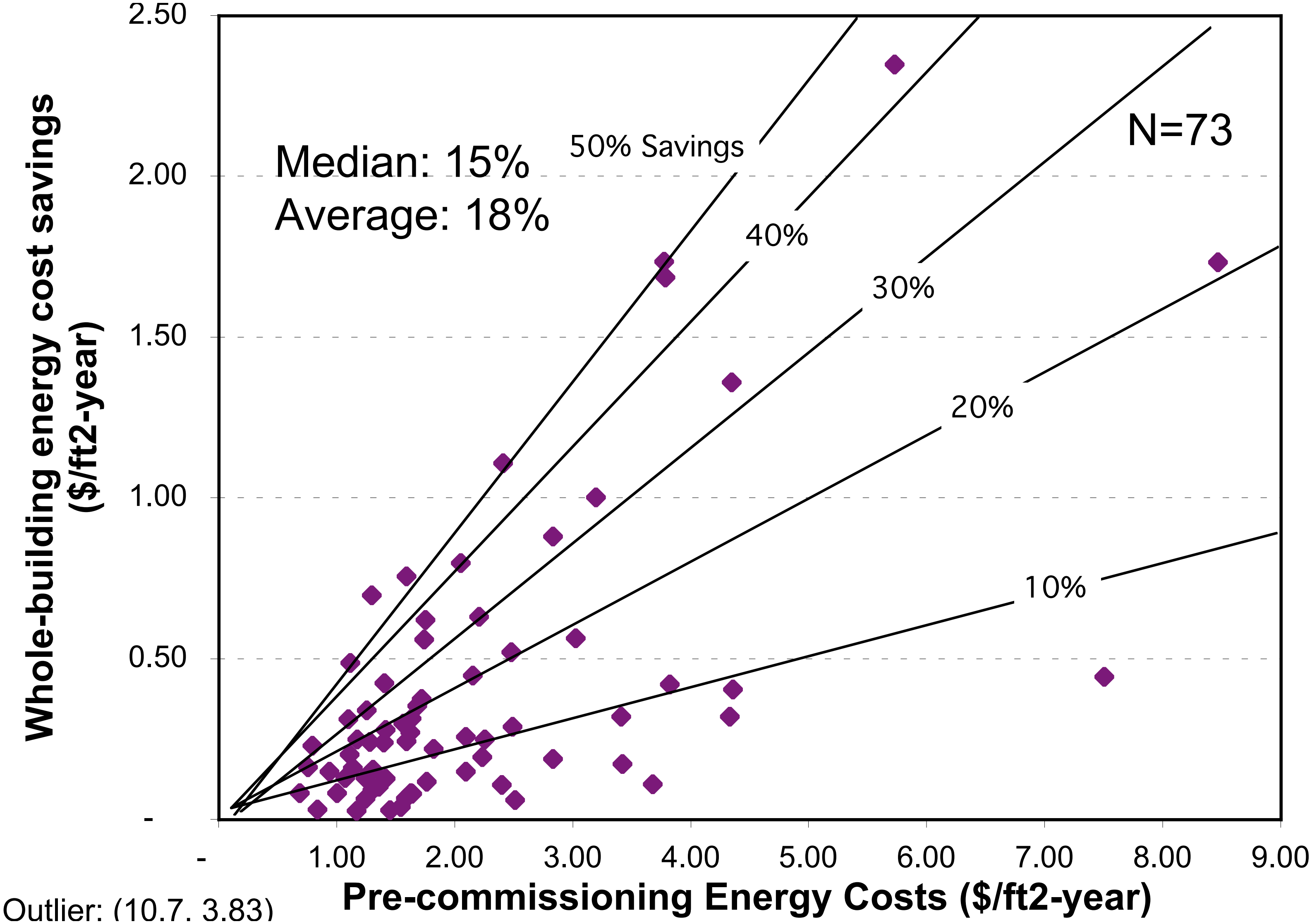


New Construction: Costs range from -1% to 2%+ of total construction cost



Inclusion of non-energy benefits (e.g. equipment downsizing, reduced callbacks, … significantly reduces costs

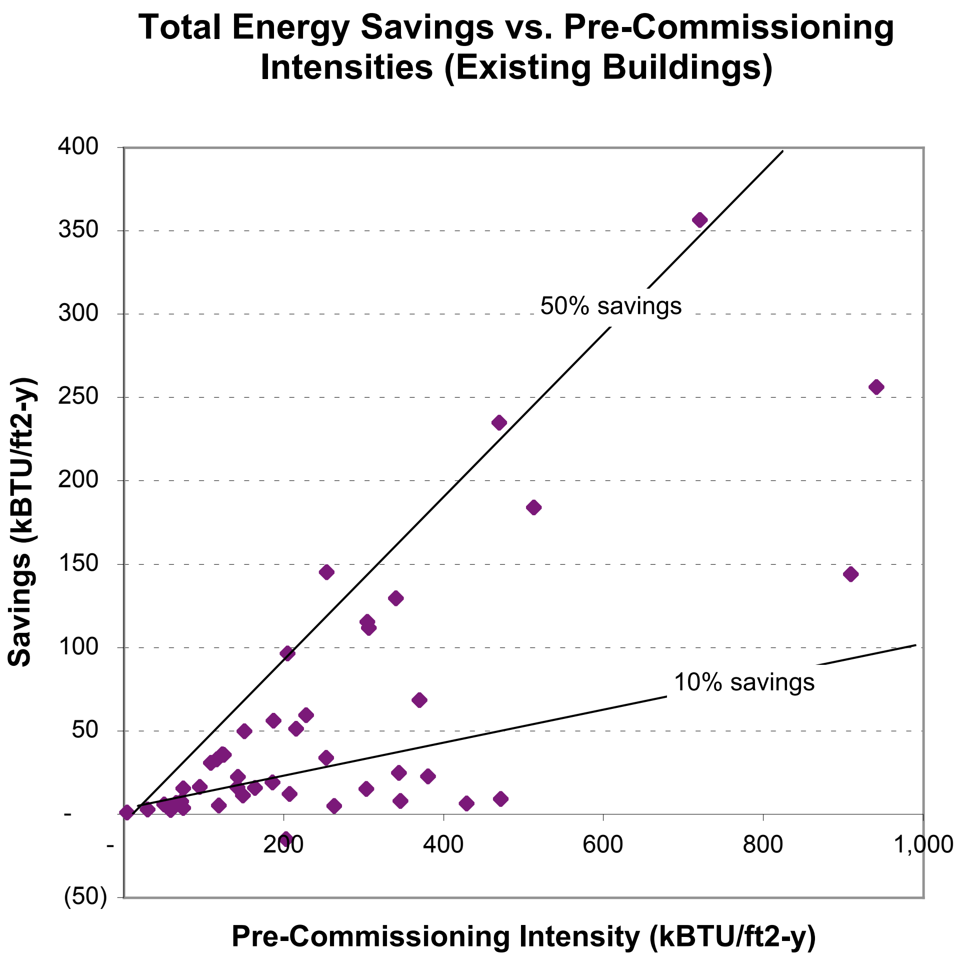
Up to 50% Whole-Building Energy Savings

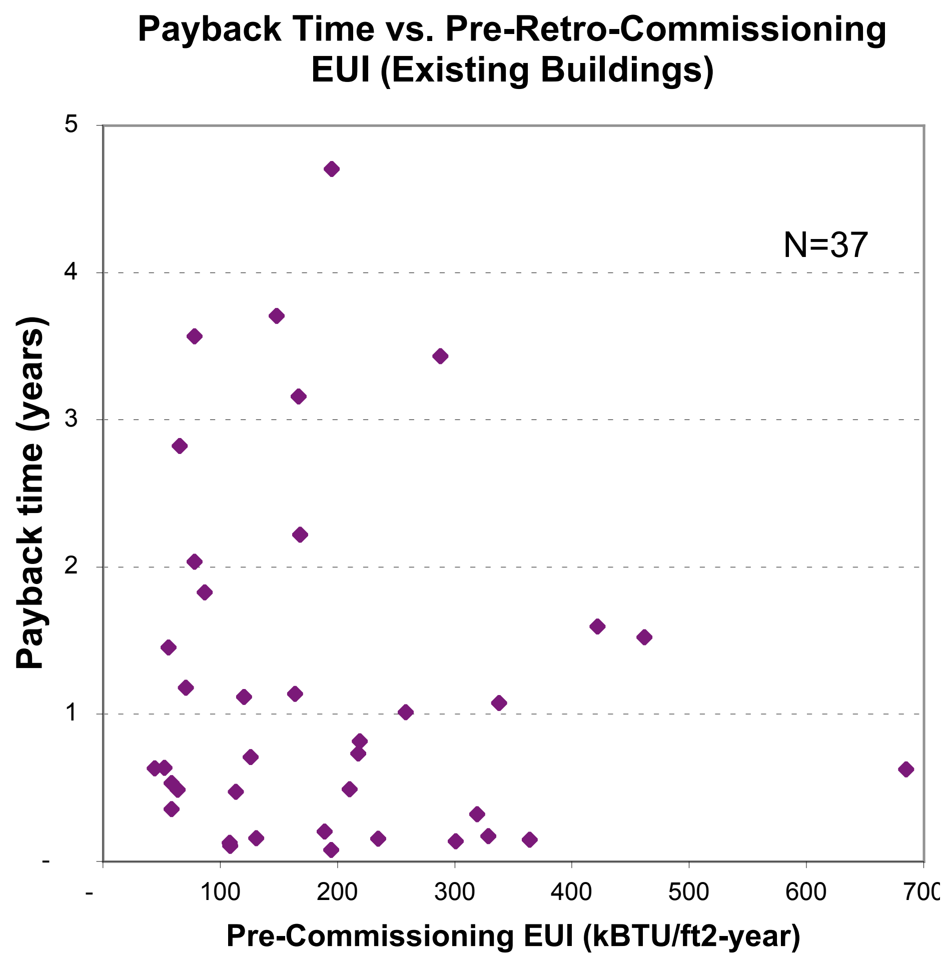


Outlier: (10.7, 3.83)

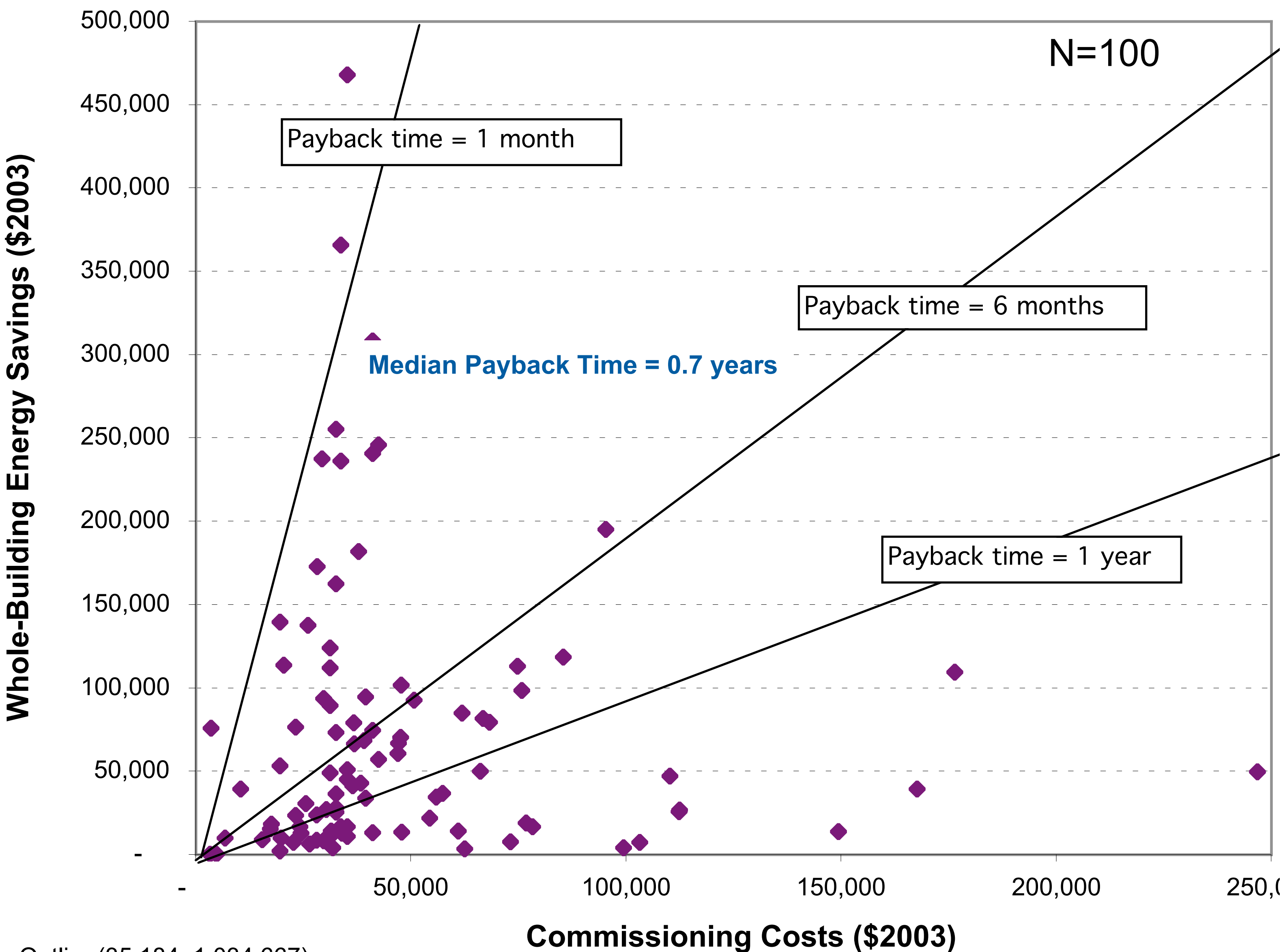
High savings even for non-energy-intensive buildings

Energy Savings & Payback Times Independent of Pre-Cx Energy Intensities





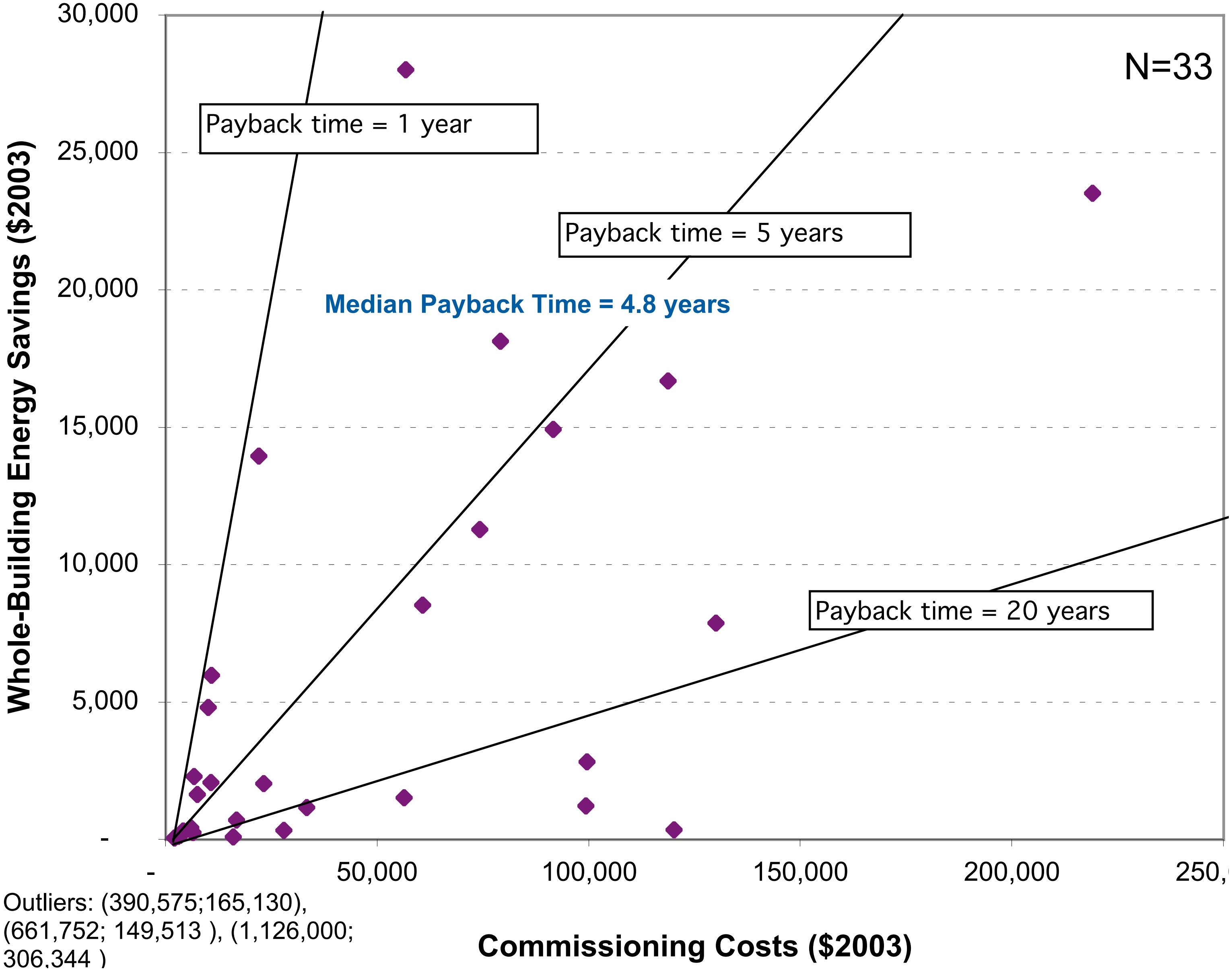
Payback Times: Existing Buildings



Outlier (35,184; 1,034,667)

Attractive payback times across range of building sizes

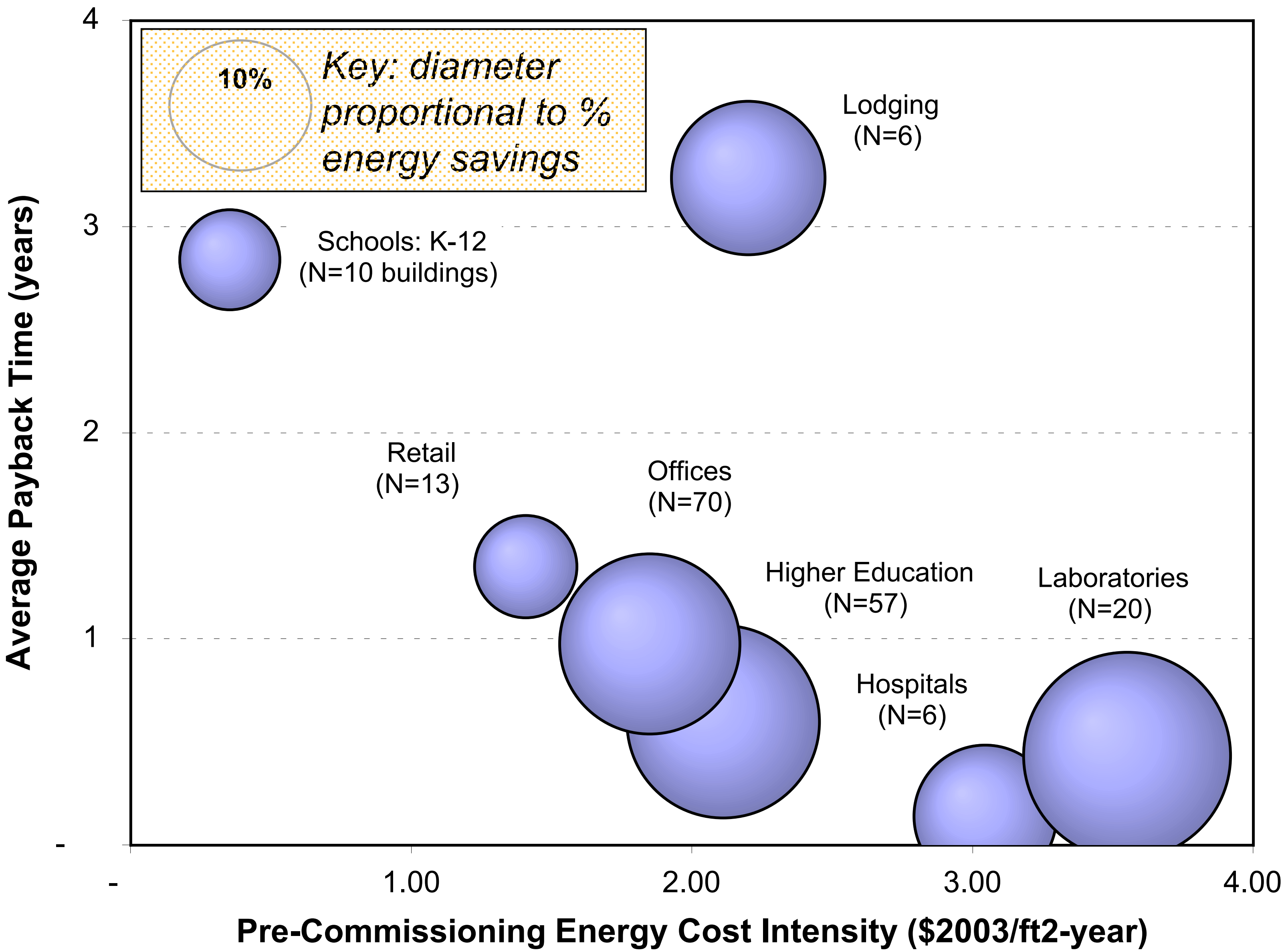
Payback Times: New Construction



Outliers: (390,575;165,130), (661,752; 149,513), (1,126,000; 306,344)

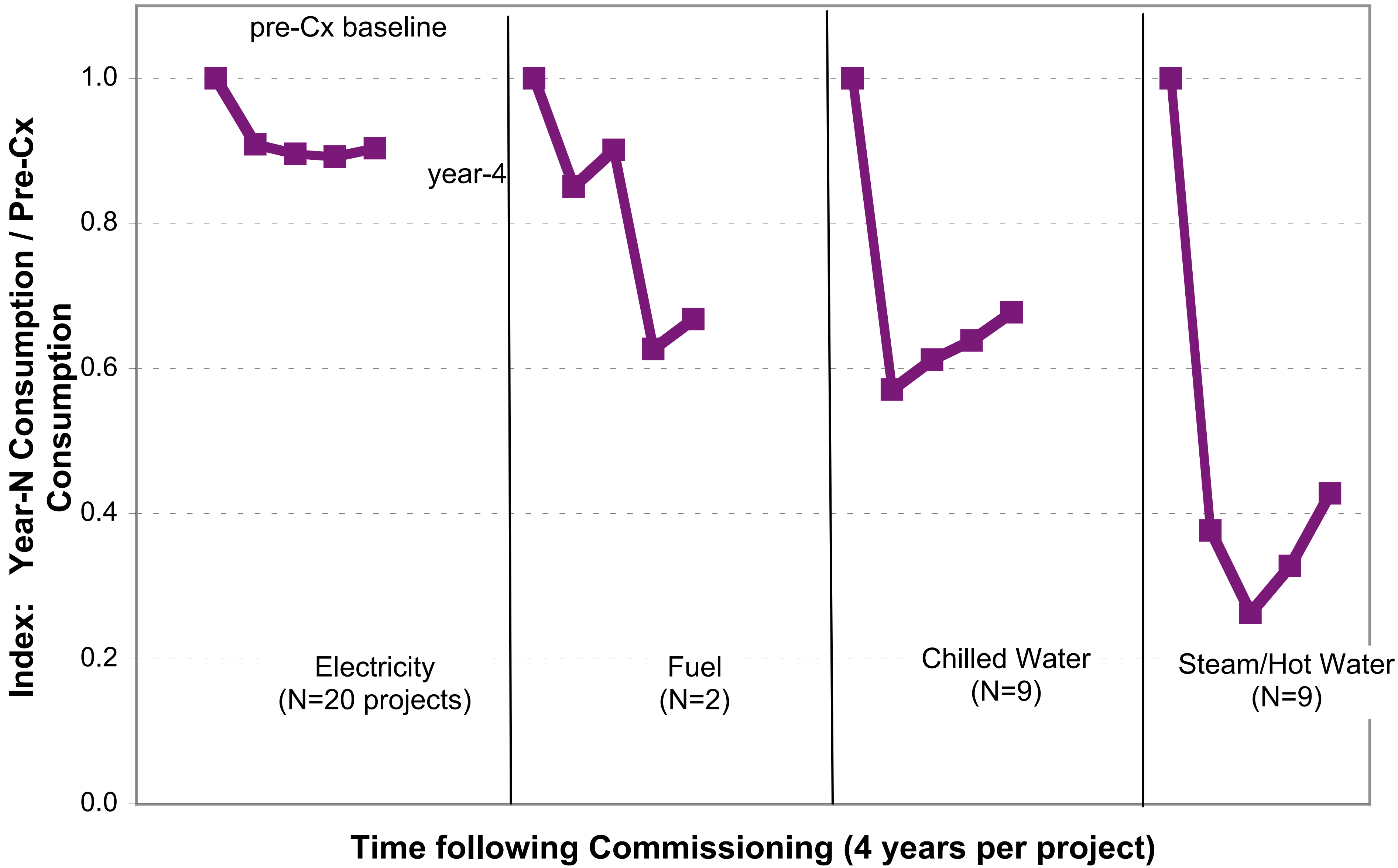
Payback times not always attractive (if NEBs excluded)

Results Vary by Building Type



Excluding non-energy impacts

Emergence & Persistence of Energy Savings



Existing Buildings vs. New Construction

- Existing buildings
  - larger
  - greater normalized energy savings
  - more cost-effective (excluding NEBs)
- New construction
  - less comprehensive
  - normalized costs higher
  - larger non-energy benefits
  - NEBs are a more important motivation for embarking on commissioning, and can go farther in offsetting the cost of commissioning
  - more deficiencies found

National Potential; National Need

- $18 billion <u>annual</u> energy savings potential (US-wide) -- *plus* non-energy benefits

- Without commissioning, many energy-efficiency projects, programs, and policies will often fall short of their goals

Recommendations

- No energy management program is complete without commissioning (in-house or outsourced)
- Invest in commissioning (existing buildings and new construction)
- Institutionalize the process
- Track outcomes, refine process

Participate in our Research:
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http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html